An EPID based method for efficient and precise asymmetric jaw alignment quality assurance

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Abstract

Purpose:

The aim of this work was to investigate the use of amorphous silicon electronic portal imaging devices (EPIDs) for regular quality assurance (QA) of linear accelerator asymmetric jaw junctioning.

Methods:

The method uses the beam central axis position on the EPID measured to sub-pixel accuracy found from two EPID images with 180 degree opposing collimator angles. Individual zero jaw position ('half-beam blocked') images are then acquired and the jaw position precisely determined for each using penumbra interpolation. The accuracy of determining jaw position with the EPID method was measured by translating a block (simulating a jaw) by known distances using a translation stage and then measuring each translation distance with the EPID. To establish the utility of EPID based junction dose measurements, radiographic film measurements of junction dose maxima/minima as a function of jaw gap/overlap were made and compared to EPID measurements. Using the method the long-term stability of zero jaw positioning was assessed for four linear accelerators over a 1-1.5 year time period. The stability at non zero gantry angles was assessed over a shorter time period.

Results:

The accuracy of determining jaw translations with the method was within 0.14 mm found using the translation stage (standard deviation of 0.037 mm). The junction doses measured with the EPID were different from film due to the non water equivalent EPID scattering properties and hence different penumbra profile. The doses were approximately linear with gap or overlap, and a correction factor was derived to convert EPID measured junction dose to film measured equivalent. Over a 1 year period the zero jaw positions at gantry zero position were highly reproducible with an average SD of 0.07 mm for the 16 collimator jaws examined. However the average jaw positions ranged from -0.7 mm to 0.9 mm relative to central axis for the different jaws. The zero jaw position was also reproducible at gantry 90 degree position with 0.1 mm SD variation with the mean jaw position offset from the gantry zero position consistently by 0.3-0.4 mm for the jaws studied.

Conclusions:

The EPID-based method is efficient and yields more precise data on linear accelerator jaw positioning and reproducibility than previous methods. The results highlight that zero jaw positions are highly reproducible to a level much smaller than the displayed jaw resolution and that there is a need for better methods to calibrate the jaw positioning.

Key Words: Asymmetric jaws, Junction dose verification, EPID

I. Introduction

Asymmetric jaws are ancillary devices used on linear accelerators that have a number of clinical applications in radiation therapy such as delineation of planned boost fields, matching of divergent fields, junction feathering, and opposed tangential fields [1].

The use of asymmetric jaw junctioning is a common technique in modern radiotherapy. The asymmetric jaws are most commonly employed such that a field is formed when one of the jaws is positioned at the central axis of the radiation field. This is commonly known as a half-beam blocked field, and is referred to in this work as a 'zero jaw position' field. A second field is then employed with the opposing jaw positioned at the central axis. The junction of the two fields is then formed by the two non-divergent jaw field edges[2]. A number of complications relating to the overlapping of adjacent radiation fields, causing an area of high dose or "hot spot", have been documented[3]. Among the most severe of these is radiation-induced myelopathy[4]. If the converse were to occur and the adjacent fields do not abut sufficiently a "cold spot" may eventuate, leading to an under-dosage affecting therapeutic outcome.

Treatment sites that commonly involve the use of matched fields include the head & neck region [5] and breast region [6]. Less common examples are treatments involving irradiation of the entire central nervous system (for example, in treating medulloblastoma) [7] and oesophageal [8] cancer. The CNS treatments are commonly feathered to reduce the effect of low or high doses at the field junctions.

Because the use of asymmetric jaws is so common and the consequences of a misaligned jaw are potentially severe there is an obvious need for a comprehensive quality assurance program. While the dosimetric impact of the field junctioning can be ameliorated by the use of feathered junctions, these are not usually employed for the most common treatments of breast and head and neck for practical reasons. The overdose and underdose have been previously reported as high as 15% per mm of jaw gap or overlap [24], [25]. Regular quality assurance of asymmetric jaws involves the testing of light and radiation field coincidence as well as film measurements of abutting fields [9].

Conventional methods for quality assurance of asymmetric jaws usually involve the irradiation of film with two abutted zero jaw position fields and visual analysis of the junction gap or overlap or dose analysis using profiles across the digitised film. These tests can be time consuming and precise knowledge of the jaw position is usually not obtained with these methods. Low junction doses can be achieved with jaws that are well aligned but with neither jaw at the correct (zero) position. However to achieve this still requires efficient methods to quantify the alignment. Errors in jaw positioning could also introduce errors that could have other consequences, for example when the jaws are used to shield critical structures such as spinal cord. The ability to efficiently determine jaw positions for both accurate jaw alignment and jaw positioning would be a valuable tool in the clinic. Data on the long-term reproducibility of asymmetric jaw positioning is also lacking. These data would facilitate the design of appropriate quality assurance tests and their frequency.

The use of electronic portal imaging devices (EPIDs) in regular quality assurance measurements has become more commonplace with their efficacy being demonstrated in a variety of applications. Studies of enhanced dynamic wedge (EDW) dosimetry[10], verification of intensity modulated radiation therapy (IMRT) treatment delivery[11], quality assurance of leaf positioning in dynamic multi-leaf collimator (MLC) treatments[12; 13; 14; 15; 16; 17; 18; 19], MLC collimator centrality[20], as well as relative measurements of beam flatness and symmetry[21] have been shown to be viable applications of EPIDs in radiation therapy. EPIDs have also been used to examine accuracy of field edge positions in the cranial match plane of tangential breast fields and supraclavicular-axillary fields using an electronic portal imaging device and match line markers placed on the skin of the patients[22].

In this work we develop and test a method for rapid and precise determination of asymmetric jaw positioning using an EPID. The method uses a precise determination of the beam central axis location and field edges to determine jaw positions to sub-mm accuracy. We use the method to monitor the long-term reproducibility of jaw positioning for four linear accelerators over an 1 to 1.5 year time interval. The ability of EPID to quantify junction doses was also investigated by comparison to film. This new method should assist with improving calibration and quality assurance procedures for these devices.

II. Methods

A. EPID-based quality assurance method

An EPID-based quality assurance procedure has been developed for dosimetric and mechanical quality assurance tests (QA) at our centre. QA images are taken using four Varian aS500 EPIDs with three having the E-Arm support positioning arms and one having the older R-Arm type. The four treatment machines comprise two Clinac 21iX and two 21eX, (Varian Medical Systems, Palo Alto, CA). Among these EPIDs there are two types of Image Acquisition Software in use (IAS2 & IAS3), however this does not affect the quality of the images gathered for this study. All images are 512×384 pixels in size (40×30 cm^2), with the EPID pixel pitch being 0.784 mm. All data were acquired with 6 MV nominal beam energy, as the methods used are not beam energy dependent. These QA images are taken on a monthly basis. A QA patient has been created in the ARIA system (Varian Medical Systems, Palo Alto, CA) with a succession of treatment beams to be imaged. The machine setup is straightforward with the gantry angle set to 0° and the EPID source to detector distance (SDD) set to 105 cm. The semi-automated ARIA treatment software cycles through the defined fields acquring an image for each. All images are acquired with integrated or dosimetric imaging mode that records all dose delivered. These images include symmetric 10×10 cm^2 photon fields taken at collimator angles of 90° and 270° to determine the central axis location as well as EPID response reproducibility, 20×20 cm^2 open and EDW fields for beam profile QA, zero jaw positioning fields and MLC positioning and IMRT QA images. The measurement and quality assurance of EDW fields using an amorphous silicon EPID has been described previously [23].

The zero jaw position fields are acquired of both upper (Y) and lower (X) jaws. Each field is 20 cm along the axis parallel to the junction and 10 cm in width in the orthogonal direction with 40 MU delivered. Each individual image is of a single jaw position e.g. X1 jaw positioned at zero, with the image acquired and stored. This would then be followed by X2 jaw positioned at zero with a second image acquired. Images are also acquired of upper and lower jaw alignment using 90 degrees of collimator rotation for one of the fields, as these junctions are commonly used in head and neck treatments to optimise MLC orientation. For all experiments the MLC was fully retracted, so the field edges are formed by the jaws alone, as would normally be done clinically.

The images are calibrated to dose using the vendors portal dosimetry system although this is not a requirement of the method. This calibration consists of a calibration factor that converts EPID grayscale to EPID dose expressed in CU units, and multiplication by a two-dimensional beam profile function. We use a flat beam profile (equal to 1 at all points) for this purpose, so the EPID profile is unaltered. The dose calibration factor is obtained by irradiation of a 10×10 cm^2 field for 100 MU at 105 cm source-detector distance and the dose value that the user wants the EPID to report for those setup conditions is entered e.g. 100 CU. The unit called CU is used by the vendors software instead of cGy. These images are exported as ASCII (or DICOM for uncalibrated) files from the vendors software and subsequently analysed using software programs that have been developed in-house.

B. CAX determination with EPID

The method developed to precisely determine the position of the radiation beam central axis (CAX) pixel location on the EPID uses MATLAB (The Mathworks, Natick, PA) [23][23][23][23][23][23][22][21][21]software to analyse two symmetric 10×10 cm^2 photon fields acquired at collimator angles of 90° and 270°. The images are first normalised using an average pixel value from a 9×9 pixel region at the approximate central axis. EPID profiles in the crossplane and inplane directions are constructed through the approximate central axis. The field edge location (50% value) is determined by linearly interpolating adjacent pixels in the penumbra. The midpoints of the crossplane and inplane profiles yield the CAX location for each image. An overall CAX point is determined by averaging results from the two 90° and 270° collimator angle images to eliminate the effect of errors in jaw positioning. This method is henceforth referred to as the 'two-field' method of CAX determination. The independence of the CAX location determined by this technique on jaw positions was investigated by comparing CAX positions obtained using symmetric and asymmetric fields of varying sizes from 10×10 cm^2 up to 16×16 cm^2.

Data for CAX position has been collected on four EPIDs. The R-Arm EPID CAX position data is highly variable due to frequent recalibrations of the Arm position and is therefore excluded from this report (the R-Arm acquired jaw position data is included). One of the E-Arm EPIDs had accumulated data over eighteen months while the other two have results for a twelve month period. These data have been analysed to determine EPID positioning reproducibility, assuming that the linear accelerator beam central axis has not varied.

C. Zero jaw position determination

As the radiation CAX has already been determined using the above method, it is possible to determine whether zero jaw positions coincide with the measured CAX and also if a hot or cold spot would arise at the junction of abutting fields. This measurement does not depend on field size as only the single jaw penumbra at the zero position is examined. The EPID measured beam profile should be the same full-width at half maximum as the profile measured in water-equivalent phantom, although the penumbral shape will vary due to the different dose-deposition kernel.

Profiles across the zero jaw position image are obtained. In this case, an initial normalisation point is user defined, with the operator being required to mark the approximate centre of each field to be analysed. The zero jaw position is then determined to sub-pixel accuracy as described above by linear interpolation of pixel values either side of the 50% relative dose value. The field centre from these detected jaw positions is subsequently used as the final normalisation point for relative junction dose assessment. As the determination of jaw position relies on the initial user-defined normalisation point the reproducibility of determined jaw positions was measured by repeated measurements of the same fields, with the user defining the centre of the field multiple times. Investigations of the reproducibility of determined jaw positions were undertaken with three separate users performing the procedure five times each.

In order to verify that the EPID-based method accurately measures jaw position an independent measure of jaw positioning was required. This was achieved using a liquid metal alloy (LMA) block with machined flat surfaces mounted on a translation stage with a resolution of 10 μm as a proxy for a collimator jaw. This was positioned on a 1 cm thick plastic shadow tray mounted to the linear accelerators accessory mount (see Figure 1).

To independently determine the radiation beam CAX the block was placed at an approximate CAX position and imaged. The collimator was then rotated through 180° and another image recorded. These two images were then analysed using MATLAB software to determine whether or not the combined profile from the two fields was uniform. The zero position was found by iteratively using this process until a uniform profile was obtained. This method of CAX determination is referred to as the 'field junction' method.

Known LMA block deviations in multiples of 0.13 mm up to 1.04 mm were then introduced into the block's position and EPID images recorded (X1 positions). Analysis was conducted to determine the differences between actual and measured translations. For each translation of the block a second image was also acquired with 180 degrees of collimator rotation to give an X2 simulated position. The block was moved backwards and forwards across the zero position to simulate gaps and overlaps in the X1 and X2 alignment.

D. Investigation of EPID junction doses

While the EPID method uses individual images of zero jaw position fields to determine individual jaw positions, it is also of interest to investigate junction doses reported by the EPID when the two abutting fields are combined. For perfect alignment of the fields, a uniform junction dose profile is expected. The junction dose is the relative decrease (minimum) in dose due to two abutting fields that overlap, or the relative increase in dose (maximum) due to two abutting fields that have a gap between them. To investigate junction doses reported by combining two EPID fields these were compared to reference measurements performed with film. An EPID image of a zero jaw position field was acquired along with a film image of the same jaw. Different overlaps/gaps were then simulated in software.

For the film measurement Kodak EDR2 radiographic film (Eastman Kodak Co., Rochester, NY) was exposed to a jaw defined zero jaw position field. The film was positioned at 100 cm from the source at 1.5 cm depth in solid water phantom blocks with 8 cm solid water backscatter (Gammex-RMI, Middleton, WI). The film was then digitized using a 16-bit DosimetryPRO Advantage film scanner (Vidar Systems Corp., Herndon, VA) at 0.08 mm resolution. Images were calibrated to dose using in-house software that corrected for film background and the non-uniform response of the scanner. The film image of the zero jaw position field was used to determine the reference junction dose versus jaw gap or overlap. This was achieved by firstly rotating the image in software by 180 degrees to create a second image simulating the opposing asymmetric jaw defined field. These two images were then added together varying the position in the axis perpendicular to the field edge of one of the images to produce a flat profile when a combined image was formed. Once this zero position was established known gaps and overlaps were introduced using the software and the resulting maximum or minimum relative junction doses were recorded.

Finally, to compare junction doses measured using the EPID to actual junction doses as measured by film the same process was applied to a zero jaw position image recorded by an EPID for the same jaw.

E. Reproducibility and accuracy of zero jaw positioning

EPID data was collected for asymmetric jaw position on three linear accelerator for a period of one year, while the fourth machine's data covers a period of 1.5 years. A shorter study of the reproducibility of the zero jaw position at gantry 90 degrees was performed. The position was measured at three different experimental sessions over a four week time period with the jaw position measured 11 times. The EPID was re-positioned at gantry 90 and the CAX position determined with the two-field method. The X1 and X2 jaws were then driven to the zero position and images acquired and this was repeated several times in each session. These jaws were used as they would be expected to be most affected by gravity. The mean and standard deviation of the measured zero jaw positions was determined.

III. Results

A. EPID-based quality assurance method

Figure 2 shows an example of the images acquired with the EPID-based QA procedure for the asymmetric jaw alignment component. The two individual zero jaw position images are shown, in this case these are X2=0 and X1=0 images (collimator = 0 degrees). The jaw positions are found from these individual images. The combined image is also shown from adding the two images, and the dose profiles from the individual and combined images.

B. CAX determination with EPID

The two-field method of determining the EPID CAX position was found to be robust (independent of collimator position), as determined using various sized symmetric and asymmetric fields from 10×10 cm^2 up to 16×16 cm^2 with the EPID position unchanged between fields. The standard deviations of the CAX position in the crossplane and inplane directions were 0.05 pixels (0.04 mm) and 0.03 pixels (0.03 mm) respectively and the maximum difference found was 0.13 mm.

Long-term EPID CAX positions (EPID arm positioning) determined using the two-field method, were found to be very consistent over the course of data collection for the E-arm type support arm. Table 1 shows summary statistics for the E-arm equipped linear accelerators. Except for one axis on one arm the standard deviation of CAX position was less than 0.2 mm, showing the E-arm is highly repoducible. The R-Arm equipped CAX data was variable due to frequent recalibrations of the arm position and is not shown. Figure 3 shows the time evolution of the measured CAX positions for the three E-arm equipped linear accelerators. The graphs in Figure 3 indicate an approximate CAX position of pixel (256,192) which is to be expected, given the aS500 EPIDs have pixel matrices of dimensions 512 × 384. The increased standard deviation of the Linac 1 y CAX coordinate can be seen to be due to a sudden change in the positioning in Figure 3. The reason for this is not clear with a change occurred in both x and y positioning at this time.

C. Zero jaw position determination

Results of inter-observer variability in determination of jaw position (the jaw positions calculated by the software are dependent on a user-defined normalisation point) showed that operators consistently picked similar points as the approximate centre of the field. Interobserver variability in point position had standard deviations of 1.8 and 5.0 pixels for the first field and 1.9 and 3.4 for the second in the crossplane and inplane directions respectively. The results of these variations on determined jaw position were negligible with variations of at most 0.03 mm in determined jaw positions.

When known translations of an LMA block acting as a proxy for a collimator jaw were introduced and analysed, results showed excellent agreement between gaps and overlaps calculated using software analysis of EPID images and the known translations themselves. No differences between the calculated and actual translations larger than 0.14 mm were detected (see Figure 4). The standard deviation of the differences between measured and actual translations was 0.038 mm. A difference of 0.1 mm in CAX position determined using the two-field method and the field junction method was noted.

D. Investigation of EPID junction doses

When digital film images of zero jaw position fields were manipulated to model gaps and overlaps the junction doses were recorded and compared to junction doses calculated using images captured using an EPID. Both film and EPID results demonstrated a nearly linear change in junction dose with gap or overlap (R^2 values of 0.9996 and 0.9953 for film and EPID results respectively) with the EPID overestimating junction doses (see Figure 5) compared to film. The film-equivalent junction dose can be found from the EPID measurement by dividing the junction dose by 1.4.

E. Reproducibility and accuracy of zero jaw positioning

Zero jaw positioning results for the four acclerators demonstrated a high degree of reproducibility (Table 2) with a RMS standard deviation of 0.07 mm for the 16 jaws studied. The range of positions of the jaw averaged 0.26 mm, with all jaws moving within a range of 0.6 mm. The average jaw positions all lie within a range of -1 to +1 mm, and the largest jaw deviation was within 1 mm. The average of the absolute values of the average positions was 0.41 mm displacement from zero position.

Figure 6 shows graphs of individual jaw deviations over the time of data collection. These clearly show that the jaw positioning is very reproducible but that the average position can be quite different from zero, suggesting that improved jaw positioning calibration is needed.

The reproducibility of jaw position at gantry 90 degrees was 0.1 mm standard deviation. There was a consistent offset of the mean jaw position at gantry 90 from gantry 0 of 0.3 mm for the X2 jaw and 0.4 mm for the X1 jaw. As the offset was similar for the two jaws the gap or overlap of the jaws was almost independent (within 0.1 mm) of the gantry angle.

IV. Discussion

Traditional methods of zero jaw positioning quality assurance can be time consuming, involving the exposure and analysis of radiographic films. These methods either visually or dosimetrically assess the junction dose from two combined fields; they do not give information on the actual jaw positions, or which of the jaws may be incorrectly positioned. The method presented in this work requires little setup and exposure time. Software analysis of results is a similarly rapid process. This method has become the regular quality assurance procedure for zero jaw positioning in our department. The efficiency also facilitates more comprehensive measurements such as comparing the junctioning of x and y jaws with little additional effort.

Analysis of calculated radiation field CAX positions on the EPID determined that EPID positioning for the E-Arm type support is highly reproducible, with the assumption being made that the positioning of the central axis of the radiation field is itself very stable. This assumption is routinely validated as part of the department’s annual quality assurance program.

A discrepancy of 0.1 mm between calculated CAX positions using the two-field method and field-junction method was noted with the LMA block. This difference most likely arises from the method used for the field junction method of CAX determination. As stated, the zero position chosen is that which displays the flattest profile, which is itself a subjective decision. Another potential source of the discrepancy is the linear interpolation of EPID penumbra which is used to determine the field edge position. As seen in Figure 2(d) this is likely to lead to small uncertainties in the field edge due to the pixel sampling distance. Spline interpolation could be considered to improve this.

Due to penumbral asymmetry a perfectly uniform dose at a field junction my never be achievable. However we found that by careful alignment of the EPID and film measured fields that junction doses of less than 1.5% overdose or underdose were achievable. The film measurements of junction doses indicated that the dose varies linearly with increasing gap or overlap. In previous reports using film dosimetry, approximately linear dose changes with increments of jaw positions of 1 mm[24] were found. For a gap or overlap of 2 mm between the jaws, the matchline dose was found to increase/decrease by 30–40%. In a similar previous investigation the amount of dose non-uniformity was quantified using both mathematical summation of dose profiles and by direct measurement of doses at the junction of the two abutted fields[25]. The dose nonuniformity with 1 mm gap/overlap was about 15%. In the present work here, it was found that a single jaw positioning error of 1 mm results in a junction dose of approximately 12%. A positioning error of 2 mm results in approximately 25% junction dose. Differences in results could be due to uncertainties in jaw positioning. These results suggest that tolerances for zero jaw positioning should be reduced with 2 mm being too large, and unrelated to the accuracy of jaw positioning achievable found here. The current level of accepted jaw positioning accuracy reflects the inability to accurately measure jaw positions rather than the actual inherent uncertainty in jaw positioning.

The EPID shows a greater response with gap/overlap than a reference dosimeter such as film which is due to the non water equivalence of the EPID materials resulting in a steeper penumbral falloff. Dividing EPID measured junction dose by a correction factor of 1.4 was found to represent film measured (gold standard) junction doses. We have previously benchmarked film penumbra measurement with diode and ion-chamber measured dose profiles and found good agreement as have others[26].

Both EPIDs and film have also been used to measure abutting MLC junctions or matchlines for MLC quality assurance[27] and during IMRT delivery[28]. Using MLC defined field edges to match photon fields has also been investigated[29] [30]. One investigation[30] found abutted fields using MLC side-by-side caused underdose of approximately 15%. Abutted fields using MLC side-by-end produced more than 10% overdose. These were improved by appropriate overlaps or shifts of the MLC positions. Due to the MLC transmission and leaf end shape, the MLC penumbra for a single leaf is generally not a symmetric function. Therefore when two sequentially MLC defined fields abut a uniform dose profile does not result. The position of the radiation field edge relative to the light field or nominal position is also problematic for MLC field junctioning.

Having demonstrated that this EPID-based method of jaw positioning was valid a long-term study of jaw positioning was undertaken. Over the course of 1 year for three linear accelerators, and 1.5 years for a fourth, results showed a high degree of jaw positioning reproducibility overall. This reproducibility was still high at gantry 90 degrees. However there was a consistent offset in the jaw positions between gantry 0 and gantry 90 of ~0.4 mm. This was consistent for both jaws so the gap or overlap of the jaws remained consistent. This offset is problematic for the junctioning of fields where the fields are at different gantry angles such as for anterior neck and lateral head fields, and will reduce the junctioning dose accuracy. Methods to reduce this could include measuring the offset of the jaws relative to gantry zero and introducing a correction into the jaw positioning software to account for this. The high level of jaw reproducibility suggests that new methods are required to calibrate the jaw positioning. Improving this calibration could have potentially positive impacts in junction doses for patient treatments. Jaw junctioning at off-axis positions should also be investigated.

V. Conclusion

A study of a novel method of conducting zero jaw positioning quality assurance was undertaken. We demonstrated that the aSi EPID support arm displayed a high degree of positioning reproducibility. The method presented demonstrates the ability to perform regular quality assurance measurements of asymmetric jaw positioning in a manner that is easier, has much higher precision and is less time consuming than existing radiographic film measurement techniques. The linear accelerator zero jaw positioning studied was found to be highly reproducible over long time periods.

VI. Acknowledgements

The authors would like to thank A/Prof Eva Bezak and staff at the Dept. of Medical Physics, Royal Adelaide Hospital for kindly manufacturing the machined LMA blocks for this study.

Tables

Table 1. Range and Standard Deviation of measured CAX positions

Linac	Data Collection Period (months)	Range of Measured CAX Positions (mm)		S.D. of Measured CAX Positions (mm)	
		x	y	x	y
1	18	0.55	1.43	0.16	0.45
2	12	0.07	0.21	0.02	0.06
3	12	0.08	0.70	0.03	0.14

	Jaw	Max (mm)	Min (mm)	Range (mm)	Average (mm)	SD (mm)	Data collection period
Linac 1	X1	0.88	0.64	0.24	0.77	0.06	1.5 years
	X2	0.72	0.51	0.21	0.62	0.07	
	Y1	-0.77	-0.44	0.33	-0.59	0.08	
	Y2	-0.92	-0.46	0.46	-0.67	0.09	
Linac 2	X1	-0.21	0.09	0.30	-0.07	0.09	1 year
	X2	-0.20	0.04	0.24	-0.12	0.06	
	Y1	0.78	0.43	0.35	0.58	0.08	
	Y2	-0.36	-0.17	0.19	-0.25	0.05	
Linac 3	X1	-0.32	-0.10	0.22	-0.20	0.06	1 year
	X2	0.56	0.43	0.13	0.46	0.03	
	Y1	0.09	-0.09	0.18	0.03	0.04	
	Y2	-0.37	-0.15	0.22	-0.26	0.05	
Linac 4	X1	0.55	0.19	0.36	0.33	0.11	1 year
	X2	-0.80	-0.24	0.56	-0.62	0.13	
	Y1	0.19	0.07	0.12	0.13	0.03	
	Y2	0.95	0.83	0.12	0.87	0.04	
	Average			0.26	0.06	0.07	

Table 2. Zero jaw positioning results summary for the four accelerators over the time period. The maximum and minimum jaw displacements from central axis are the first two columns, where negative position denotes travel over the central axis. This is followed by the range of displacement. The average jaw position is in the fourth column, and the standard deviation of jaw positions in the fifth column. All values are in mm.

Figures

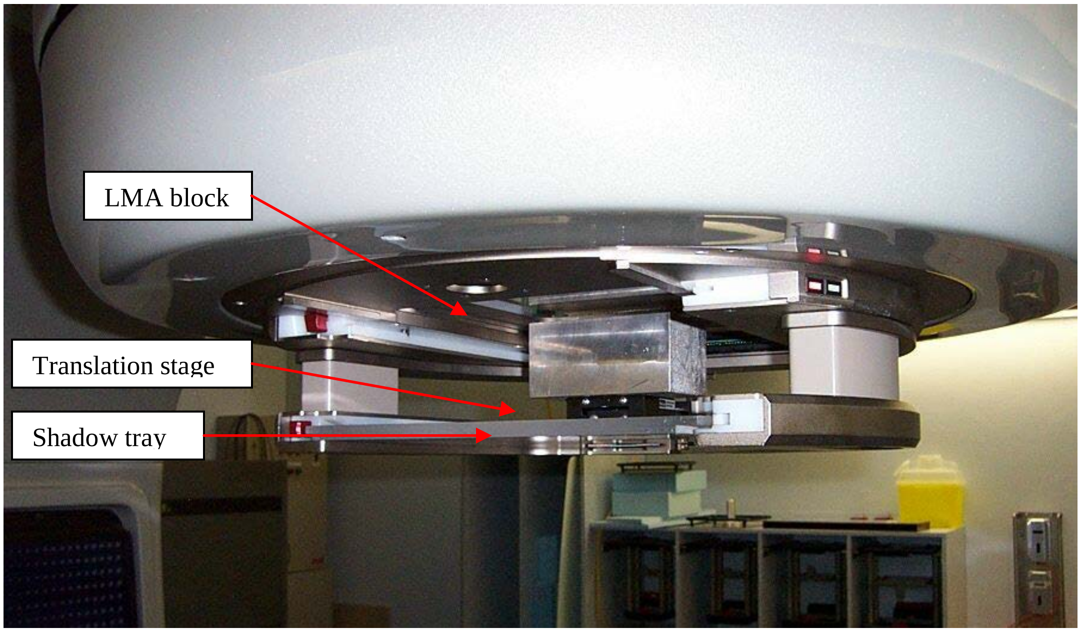


Figure 1. Experimental setup for field junction CAX determination experiment

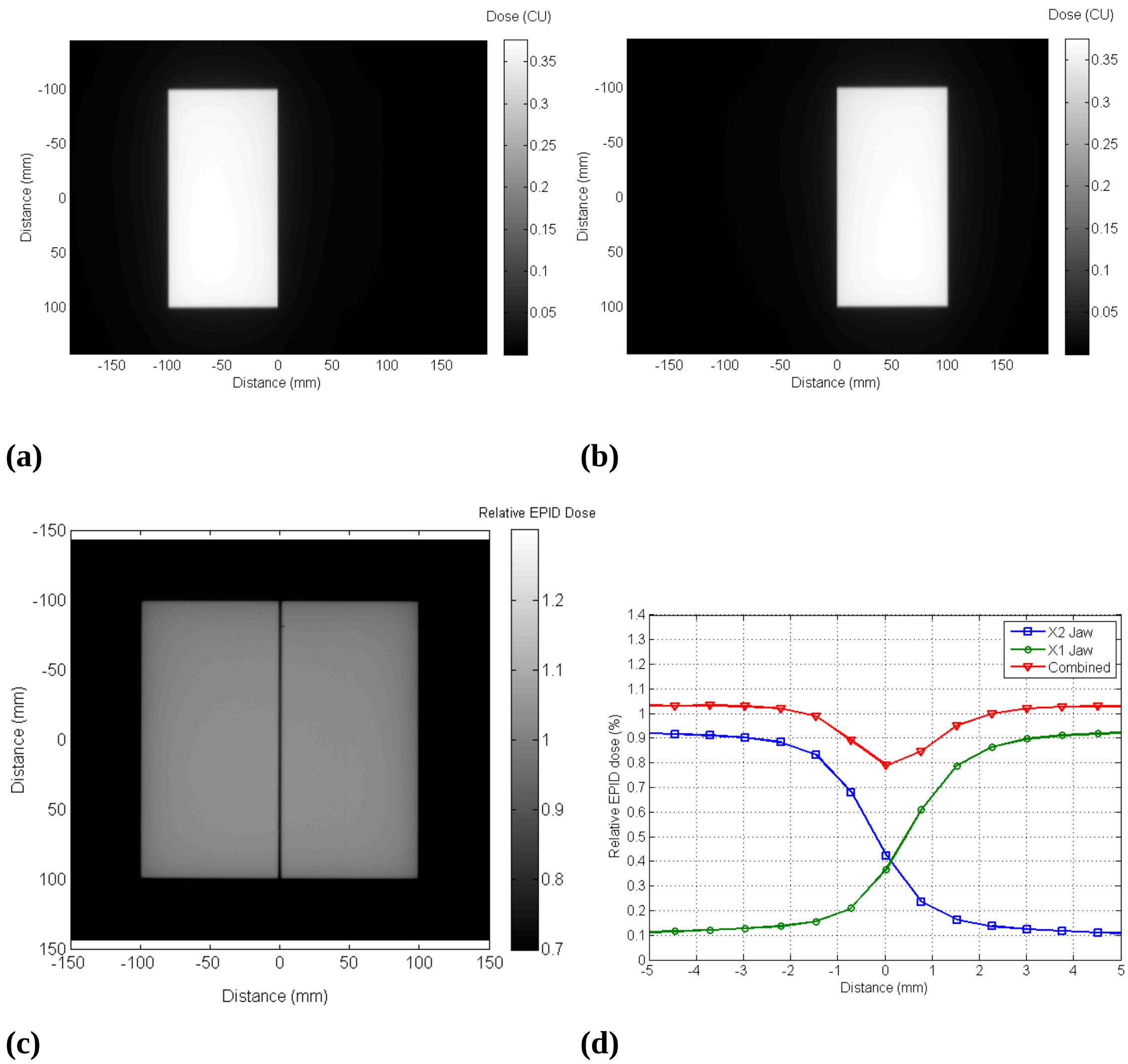
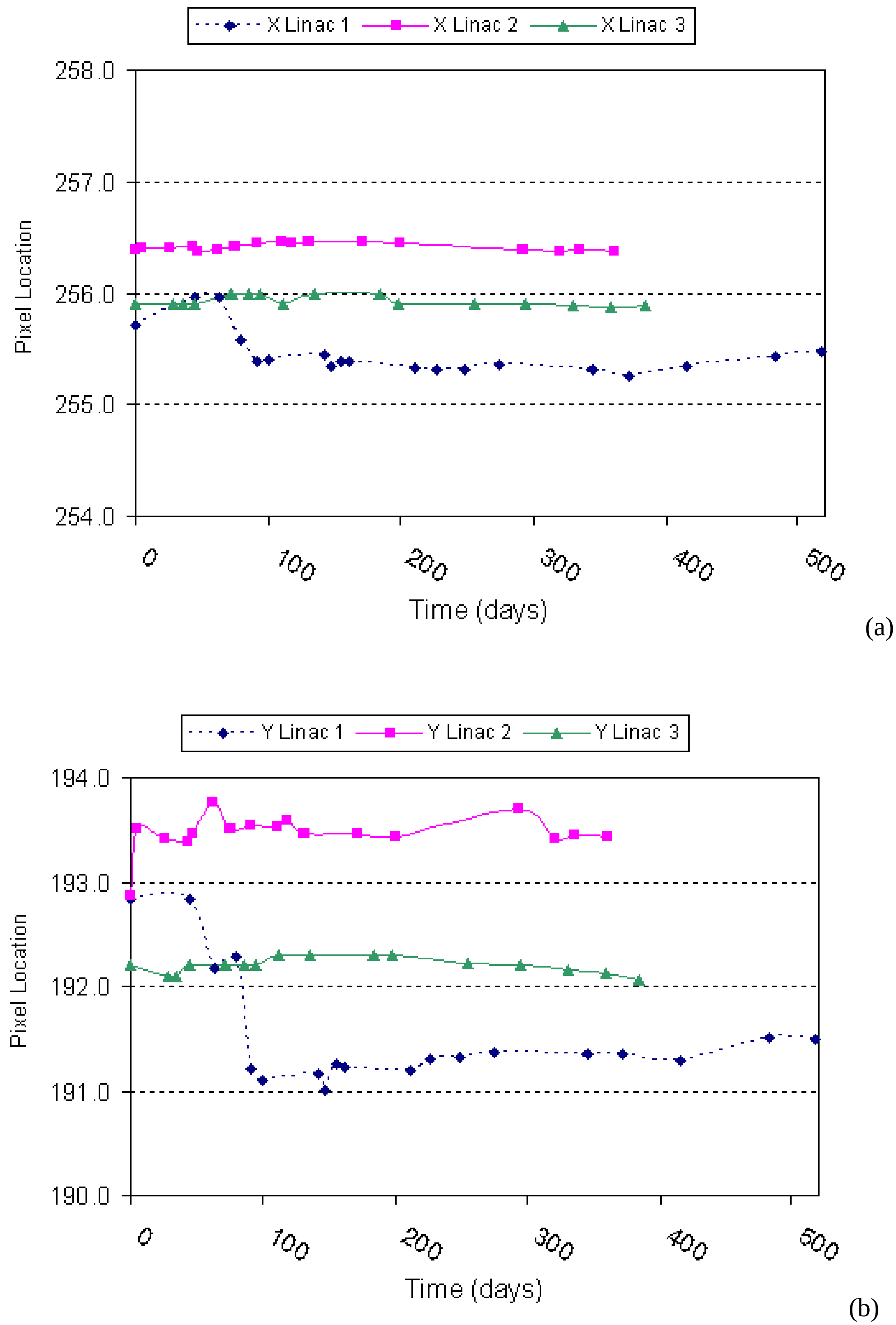
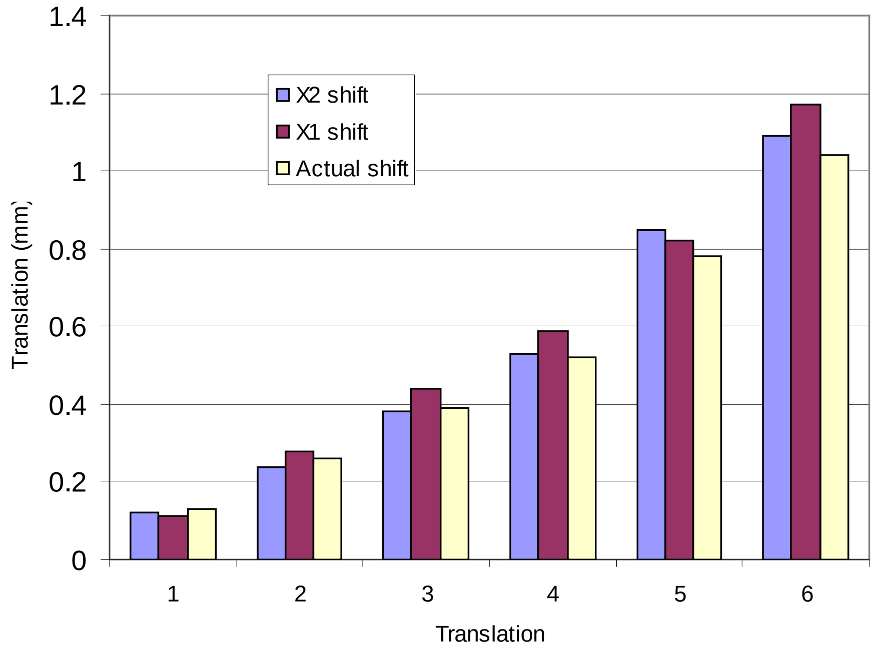


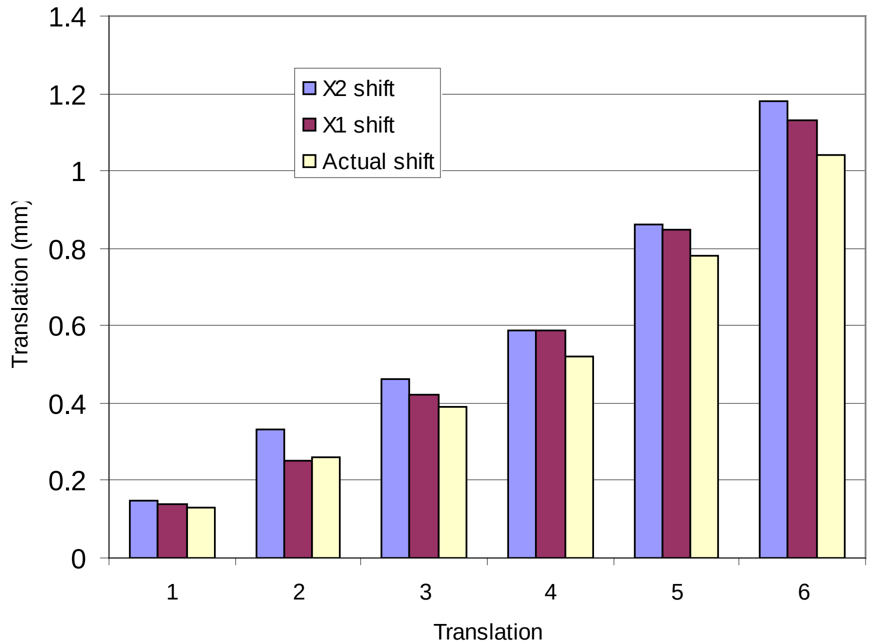
Figure 2. Example of graphical output of EPID based asymmetric jaw QA software module; (a) Zero jaw position image 1 (X2 jaw=0), (b) Jaw image 2 (X1 jaw=0), (c) combined image, (d) relative EPID dose profiles of individual and combined images. The individual images are used to determine jaw position, while the combined image can yield junction dose information.



490 **Figure 3.** Time evolution of CAX positioning on three different linear EPIDs; a) Crossplane, b) Inplane



(a)



(b)

Figure 4. Measured block (jaw) displacements versus actual displacements for a) Overlaps, b) Gaps.

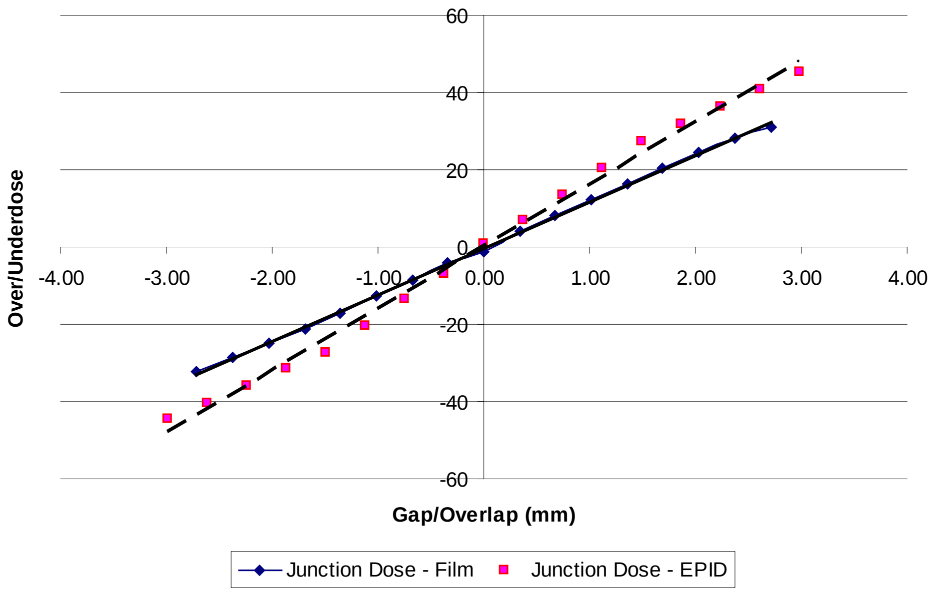
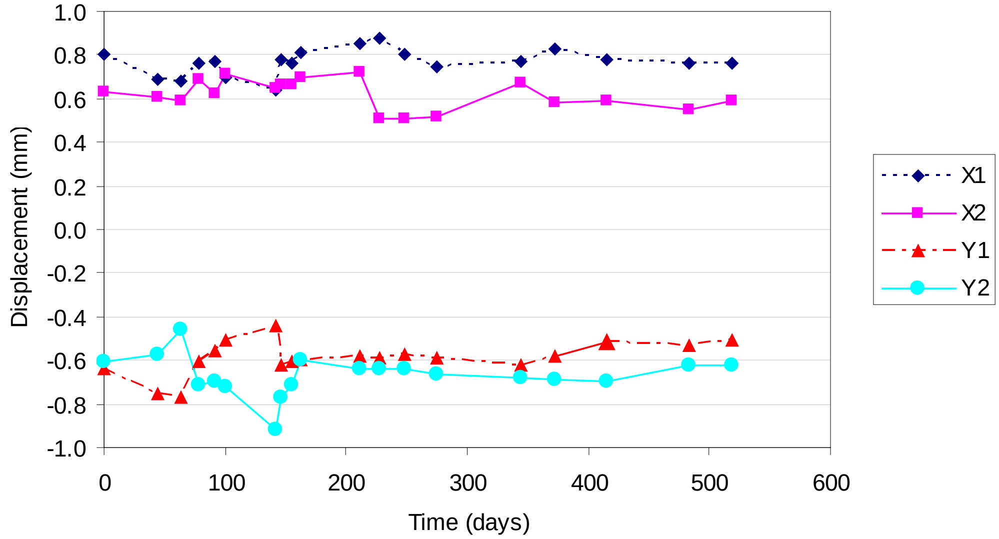
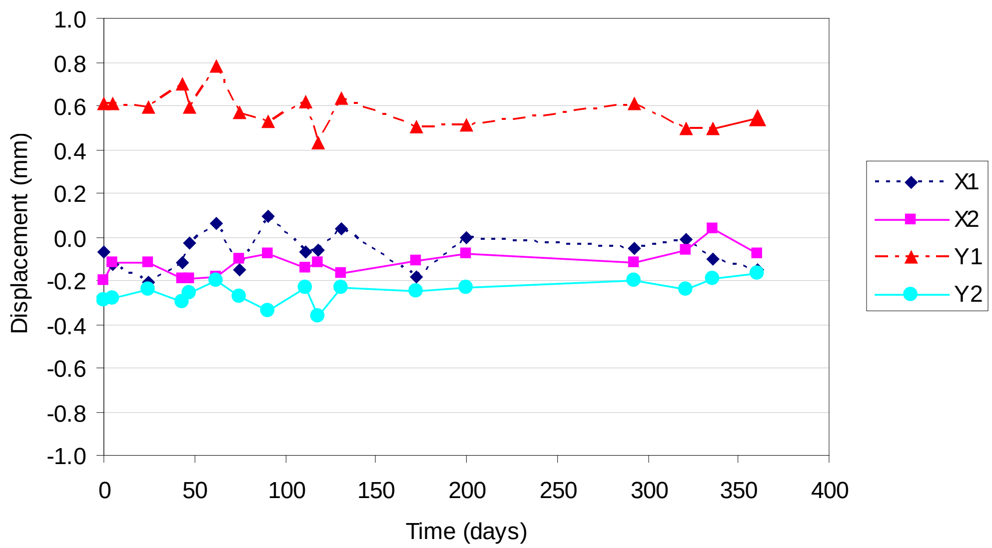


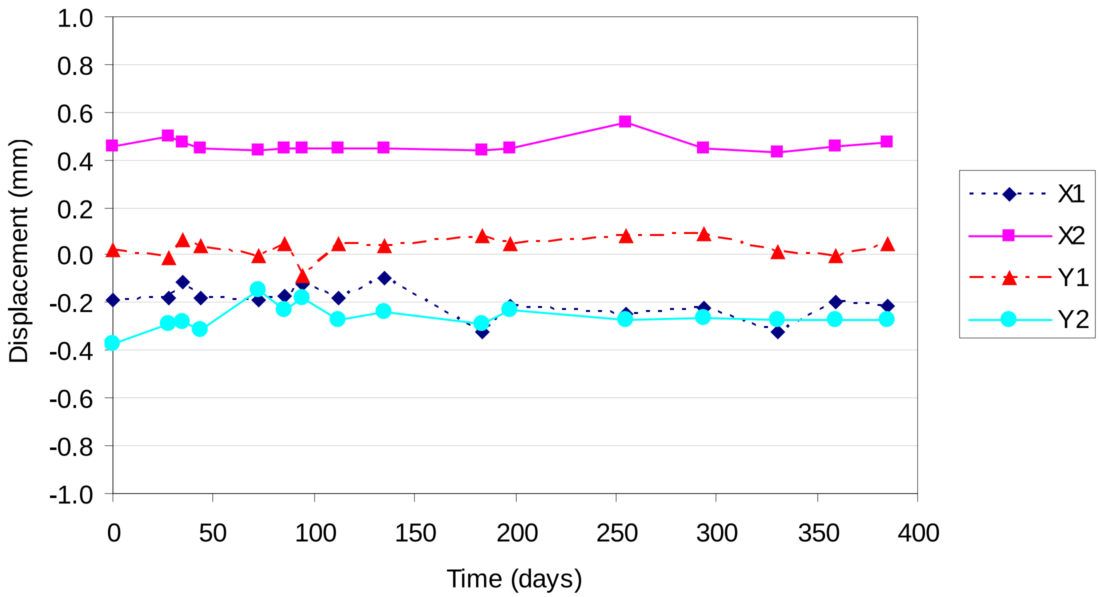
Figure 5. Junction doses as a function of gap/overlap for radiographic film and EPID images


Displacement (mm)
1.0
0.8
0.6
0.4
0.2
0.0
-0.2
-0.4
-0.6
-0.8
-1.0
0
100
200
300
400
500
600
Time (days)
X1
X2
Y1
Y2

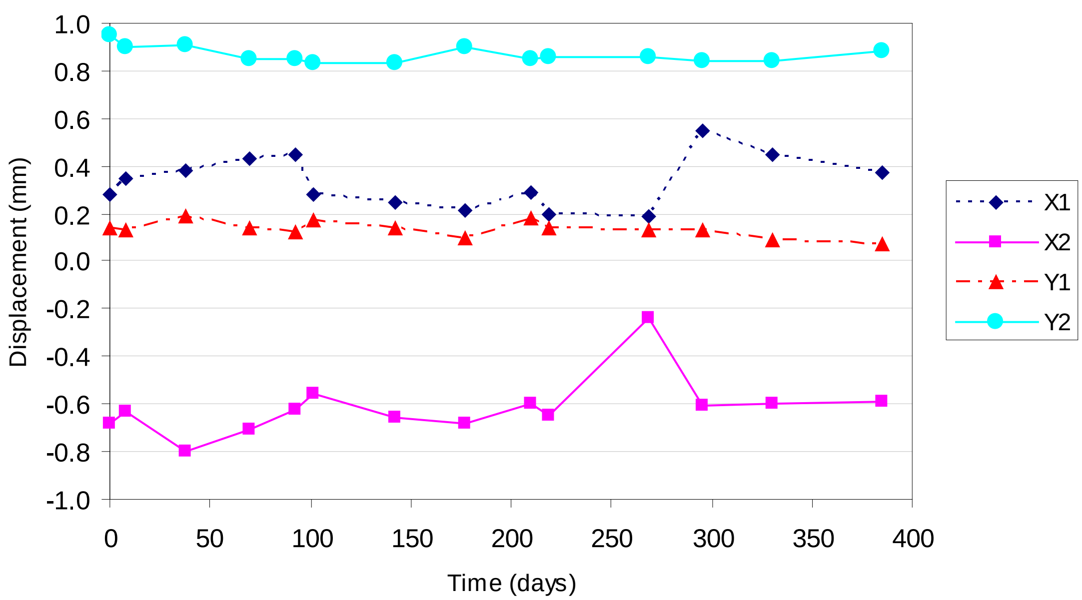
(a)


Displacement (mm)
1.0
0.8
0.6
0.4
0.2
0.0
-0.2
-0.4
-0.6
-0.8
-1.0
0
50
100
150
200
250
300
350
400
Time (days)
X1
X2
Y1
Y2

(b)



(c)



(d)

Figure 6. Time evolution of individual jaw deviations from true zero on four different linear accelerators (a: Linac 1, b: Linac 2, c: Linac 3, d: Linac 4)

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